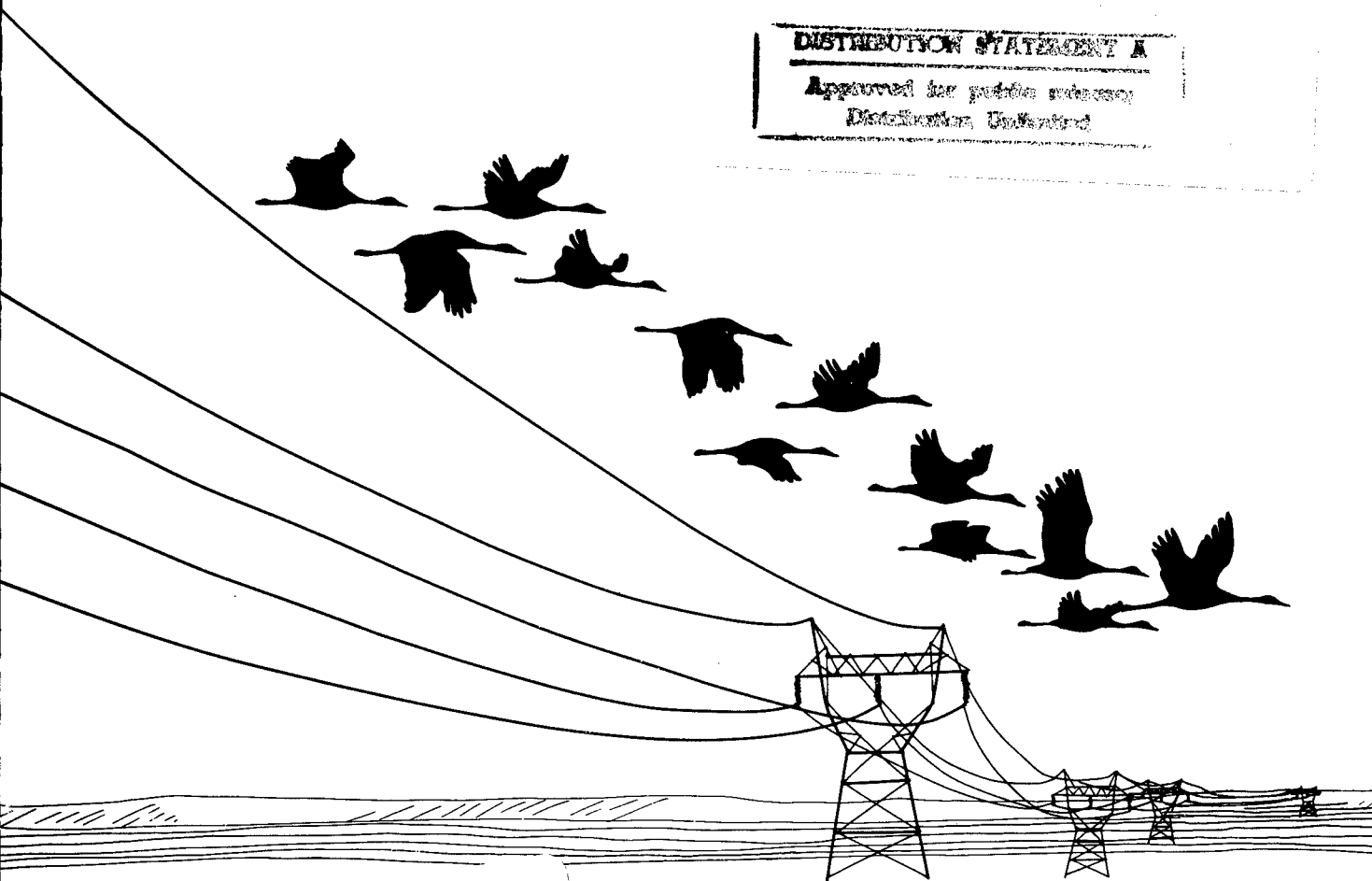


Bird Behavior and Mortality in Relation to Power Lines in Prairie Habitats

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By Craig A. Faanes

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Bird Behavior and Mortality in Relation to Power Lines in Prairie Habitats

by

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Abstract

Research was conducted to determine the magnitude of avian mortality caused by power transmission lines in prairie habitats during the two spring and two fall migration periods between July 1980 and May 1982. Searches for dead birds were made at least twice weekly during each migration period. Study sites were selected to include "worst-case" situations involving potentially large concentrations of birds.

In total, 633 dead birds were found beneath 9.6 km of power lines. About 81% of the birds were found during fall migration. Removal of birds by scavengers was of minor, although local, importance, and observer error in finding birds was greatest in areas of dense vegetation. Total kill was estimated at 1,332 birds.

Data were gathered on more than 7,000 bird flights observed in the vicinity of the power lines. Sixty-eight percent of the birds did not respond to the presence of the power lines. Flaring and climbing over the conductor or overhead ground wire occurred in about 25% of the flights. One hundred nine birds in 82 flocks were observed to collide with a power line. Of these birds, 87% flared to climb over the power line before colliding. The overhead ground wire was responsible for most deaths, as 102 of 109 birds collided with it.

Whereas none of the mortality observed was considered to be biologically significant at the particular sites examined, the cumulative effect of mortality sustained from collisions with power lines may be important, particularly to populations of rare or endangered birds.

For most regions of the United States, no studies have examined the significance of wire strikes as a mortality factor in bird populations. Electric companies are concerned about the paucity of data on bird losses that may be occurring because of the increasing numbers of power lines. Although not considered a national problem

(Nagel 1978), bird collisions with electric transmission lines occur frequently and provided the impetus for this study. The need for additional information has increased with energy development in recent years, accompanied by construction of additional power lines transporting electricity to distant population centers.

Available literature suggests that waterfowl casualties tend to be isolated events; additionally, losses of migrating passerines have been reported (Stout and Cornwell 1976). Poor light and inclement weather, particularly wind and fog, may increase the number of wire strikes (Krapu 1974; Stout and Cornwell 1976). Although occurrences of birds striking wires are common, most are unnoticed and unreported (Cornwell and Hochbaum 1971). Public awareness of the bird strike problem is diminished because most power lines are in remote areas, and dead birds are readily concealed by marsh and upland vegetation. Predators and scavengers frequently remove injured and dead birds from these areas, further reducing the apparent size of this loss.

Meyer (1978) and James and Haak (1979) reported that avian mortality from power line strikes in the Pacific Northwest was not biologically significant. Their research, however, pointed out that a measurable amount of mortality did occur, and methods were sought to reduce it (Beaulaurier 1981). Malcolm (1982) encountered

large numbers of wire-killed birds at a Montana wetland.

During 1980-82, I studied the effect of power transmission lines on bird populations in North Dakota. Study sites were selected to represent "worst-case" situations. My original impetus for this research was to determine if avian mortality was occurring along portions of power lines that crossed areas where large numbers of birds were present. Study sites represented the three major natural communities of the northern Great Plains region: grasslands, wetlands, and woodlands. My objectives were to (1) determine the magnitude of bird mortality caused by collisions with power lines at selected sites, and (2) identify factors contributing to this mortality. Support towers for the two types of lines (400-kV DC and 230-kV AC) studied are illustrated in Fig. 1.

Names of bird species used follow the American Ornithologist's Union checklist (A.O.U. 1983). Plant species names follow Stewart (1975).

Study Areas

Water Bird Concentration Areas

Cherry Lake

The Cherry Lake site is about 7 km northwest of Dawson, Kidder County, North Dakota (Fig. 2). About 1.9 km (five spans) of transmission line were studied (Fig. 3). The site was crossed by a single-circuit 230-kV AC line (three conductors) in a flat configuration suspended on self-supporting steel lattice towers (Fig. 1). One tower on span 1 was guyed.

Habitats associated with this site were predominantly heavily grazed upland native prairie, cropland (including wheat [*Triticum vinter*] and summer fallow), and emergent aquatic vegetation. Cherry Lake is a large class V (Stewart and Kantrud 1971) alkali wetland. Vegetation along the periphery of the lake was sparse because of the high salt content. Saltwater widgeongrass (*Ruppia maritima*) was the main submerged aquatic species. Numerous small fens (class VII in Stewart and Kantrud 1971) and several freshwater lakes occurred along the northern border of the lakes. Vegetation of these wetlands beneath the power line consisted of dense growths of hardstem bulrushes (*Scirpus acutus*) and cattail (*Typha* sp.).

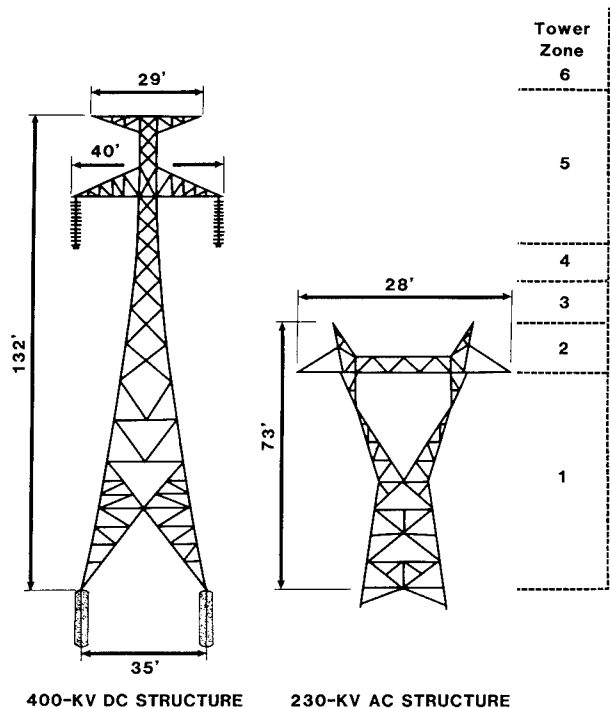


Fig. 1. Dimensions of typical support towers for 400- and 230-kV power transmission lines. Also shown are the tower zones used for recording bird behavior in flight.

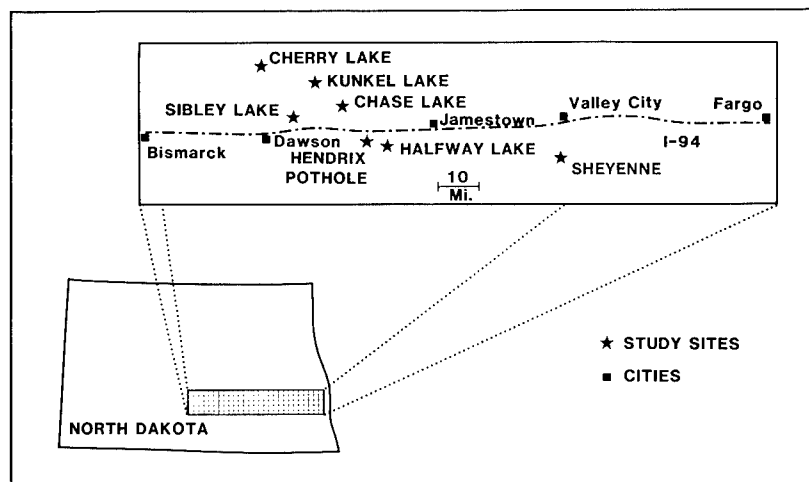


Fig. 2. Geographic location of the seven study sites in south-central North Dakota.

Bird use of this site was characterized by concentrations of sandhill cranes (*Grus canadensis*) from late August to mid-October and large populations of various shorebirds from August to mid-September. No concentrations of waterfowl were noted, except for occasional flocks of snow (*Chen caerulescens*) and Canada geese (*Branta canadensis*) in late October.

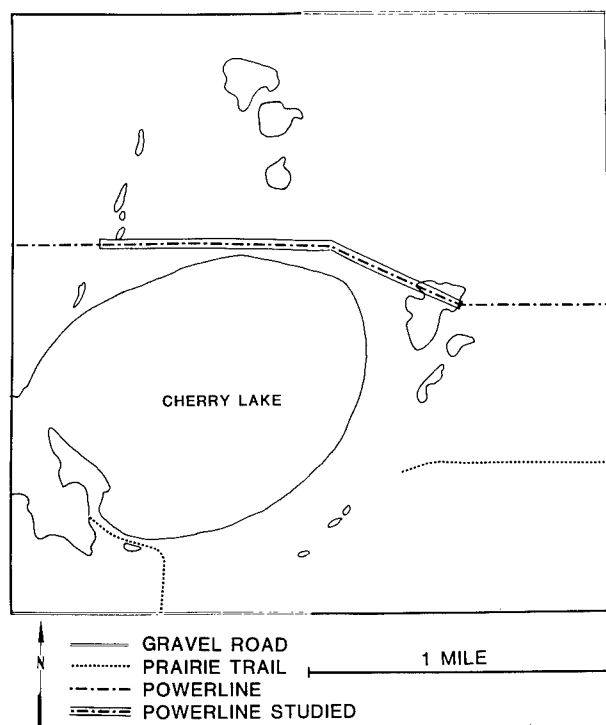


Fig. 3. Location of the power line corridor at the Cherry Lake study site.

Kunkel Lake

The Kunkel Lake site is about 10 km south of Lake Williams, Kidder County, North Dakota (Fig. 2). About 1.1 km (three spans) of line were studied (Fig. 4). The site was crossed by a single-circuit 230-kV AC line (three conductors; Fig. 1).

Habitats associated with this site were predominantly cropland, heavily grazed upland native prairie, and emergent aquatic vegetation. Kunkel Lake is a large class V (Stewart and Kantrud 1971) wetland. Emergent vegetation is generally lacking along the periphery of most of the wetland. However, subsurface conditions are apparently less alkaline. A lush growth of cattails and hardstem bulrushes grew along the northern shoreline. The shoreline turned sharply northward along the northeastern corner of the wetland, and the emergent vegetation grew to within 50 m of a fresh (class IV) wetland. One span of the power line crossed the area of emergent vegetation.

Avian use of Kunkel Lake was characterized by concentrations of Franklin's gulls (*Larus pipixcan*) during August and early September, and sandhill cranes and Canada geese during late September through October. Moderate numbers of other waterfowl and shorebirds occurred throughout the study period.

Upland Native Prairie and Water Bird Concentration Areas

Chase Lake National Wildlife Refuge

The Chase Lake National Wildlife Refuge site is about 20 km southwest of Woodworth, Stuts-

man County, North Dakota (Fig. 1). About 1.8 km (five spans) of line were studied (Fig. 5). The site was crossed by a single-circuit 230-kV AC line (three conductors; Fig. 1).

Habitats associated with this site consisted of mixed-grass native prairie and various introduced grass species. The power line crossed within 0.4 km of Chase Lake, a large class V wetland. The refuge is used by a large breeding colony of American white pelicans (*Pelecanus erythrorhynchos*) and other water birds. Because of the proximity of the lake to the power line corridor, Chase Lake served as a study site for both native upland prairie and water bird concentration areas.

The Chase Lake site supported a varied avifauna in relation to the diversity of available habitats. Particularly prominent in the grasslands were western meadowlarks (*Sturnella neglecta*), grasshopper sparrows (*Ammodramus savannarum*), and eastern kingbirds (*Tyrannus tyrannus*). The lake supported populations of pelicans, California gulls (*Larus californicus*), double-crested cormorants (*Phalacrocorax auritus*), and American avocets (*Recurvirostra americana*) during and immediately following the breeding season. During spring and fall migration periods, use of grasslands by passerines was relatively low. The lake, however, received heavy use by colonial nesting water birds, shorebirds, and waterfowl.

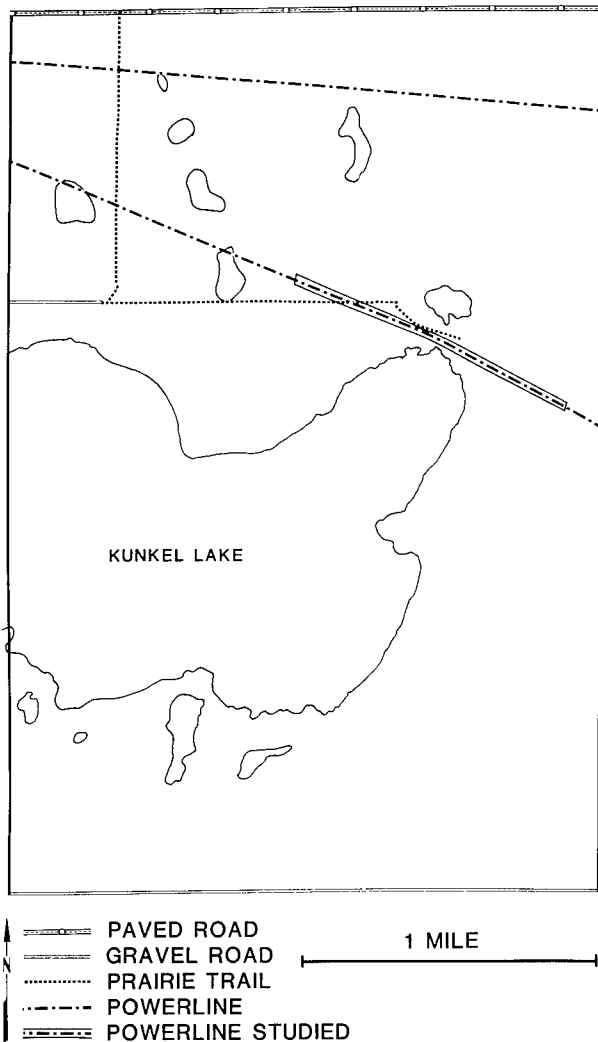


Fig. 4. Location of the power line corridor at the Kunkel Lake study site.

Sibley Lake

The Sibley Lake site is about 6.5 km north of Dawson, Kidder County, North Dakota (Fig. 1). About 1.8 km (five spans) of line were studied (Fig. 6). The site was crossed by a bipolar 400-kV DC line (four conductors in two bundles) in a flat configuration suspended on self-supporting steel lattice towers (Fig. 1).

The principal habitat at the site was heavily grazed native prairie. Adjacent lands near the site were predominantly used for wheat or summer fallow. A large class V wetland (Stewart and Kantrud 1971) occurred within 0.8 km of the study site. Populations of migrant Canada geese, sandhill cranes, and double-crested cormorants used Sibley Lake and adjoining fields and wetlands in fall. Because of the proximity of the wetland to the power line, Sibley Lake was considered a study site for both upland prairie and water bird concentration areas.

Grazing of the native grassland reduced its attractiveness to many typical grassland nesting species, although horned larks (*Eremophila alpestris*) and chestnut-collared longspurs (*Calcarius ornatus*) were present. Sibley Lake has been known to support unusually large numbers of migrant water birds in past years. In late September 1979, about 15,000 redheads (*Aythya americana*), 5,000 snow and Canada geese, and sandhill cranes were present. Use of the lake by migrant water birds during the study varied with water conditions. In fall 1981, large numbers of birds were attracted to the exposed shorelines, which were extensively used as roost sites.

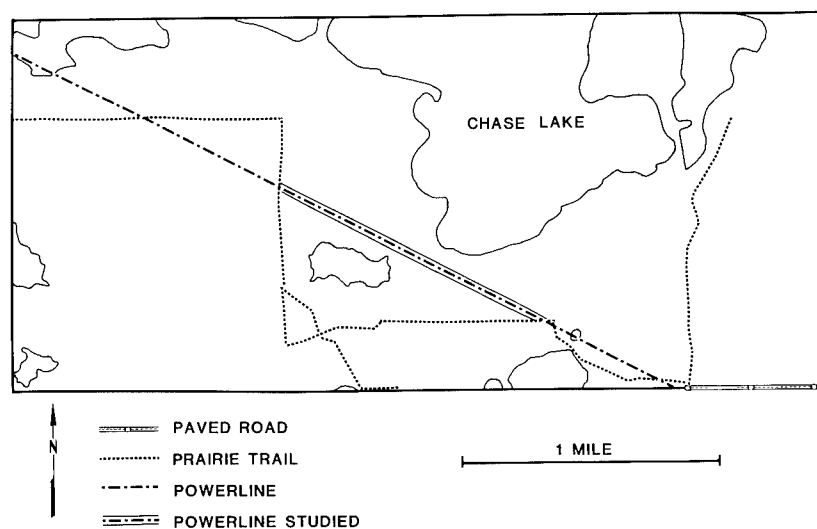


Fig. 5. Location of the power line corridor at the Chase Lake study site.

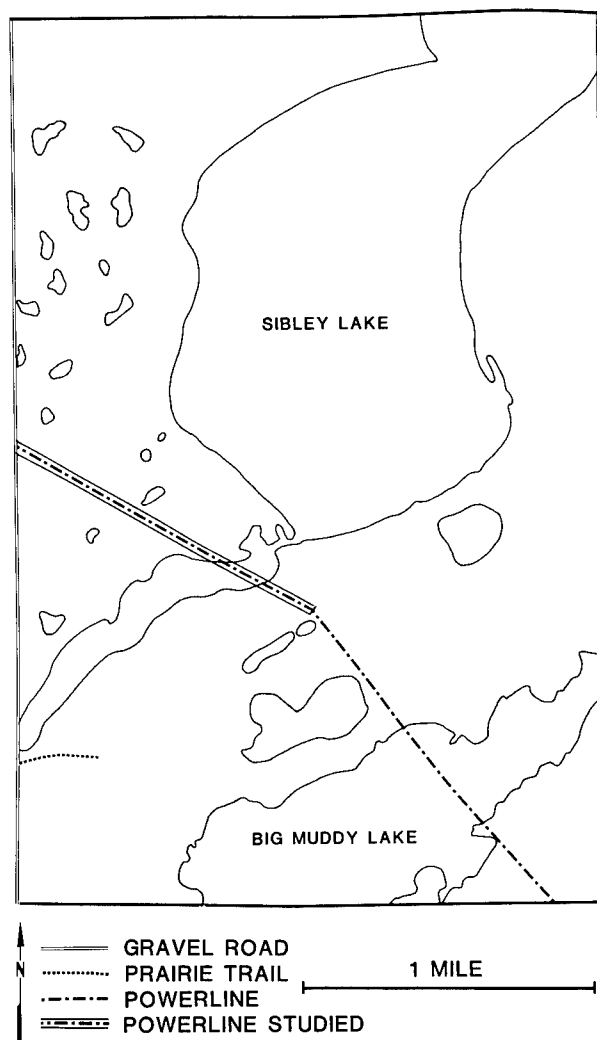


Fig. 6. Location of the power line corridor at the Sibley Lake study site.

Water Bird Production Areas

Halfway Lake

The Halfway Lake site is about 8 km east of Medina, Stutsman County, North Dakota (Fig. 1). About 1.2 km (five spans) of line were studied (Fig. 7). The site was crossed by a single-circuit 230-kV AC line (three conductors; Fig. 1).

The primary habitat associated with this site was moderately grazed native prairie. Interspersed throughout this pasture were nine class III wetlands which held water throughout late summer and fall. Emergent vegetation in these wetlands consisted of cattails, bulrushes, and sedges.

Avian use of the wetlands during the study was limited, primarily because of the fresh conditions of the water. Blue-winged teal (*Anas discors*) and mallards (*A. platyrhynchos*) were the most frequently encountered species. Each year occasional mixed foraging flocks of red-winged blackbirds (*Agelaius phoeniceus*) and yellow-headed blackbirds (*Xanthocephalus xanthocephalus*) were observed in September and early October.

Hendrix Pothole

The Hendrix Pothole site is about 3 km southwest of Cleveland, Stutsman County, North Dakota (Fig. 1). About 0.7 km (12 spans) of line were studied (Fig. 8). This site consisted of one class IV wetland bordered on the west by a gravel road, and surrounded on the north, east, and south by a single-strand 12-kV distribution line supported by single wood poles.

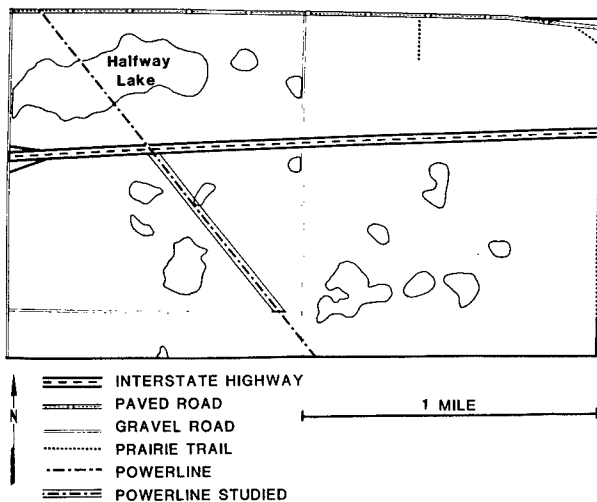


Fig. 7. Location of the power line corridor at the Halfway Lake study site.

Habitats of the study area were predominantly wheat fields that occupied the uplands adjacent to the wetland. Wetland vegetation consisted of cattails around the periphery of the wetland and various submerged aquatic species in the marsh center.

Avian use of this site was dominated by waterfowl (particularly mallards, northern pintails [*Anas acuta*], and blue-winged teal), American coots (*Fulica americana*), and mixed flocks of red-winged

blackbirds and yellow-headed blackbirds. Occasional use was made by pied-billed (*Podilymbus podiceps*) and eared grebes (*Podiceps nigricollis*) and California gulls during September.

Riparian Habitat

Sheyenne River

The Sheyenne River site is about 14 km south of Valley City, Barnes County, North Dakota (Fig. 1). About 1.1 km (four spans) of line were studied (Fig. 9). The site was crossed by a single-circuit 230-kV AC line (three conductors; Fig. 1).

Habitats associated with this site included a wheat field and ungrazed floodplain forest characterized by American elm (*Ulmus americana*), box elder (*Acer negundo*), and green ash (*Fraxinus pennsylvanica*). The corridor occupied by the power line crossing was made up of numerous patches of western snowberry (*Symphoricarpos occidentalis*) and shrub-sized box elder.

Passerine birds characterized this site including American robins (*Turdus migratorius*), black-capped chickadees (*Parus atricapillus*), white-breasted nuthatches (*Sitta carolinensis*), red-eyed vireos (*Vireo olivaceus*), common yellowthroats (*Geothlypis trichas*), and clay-colored sparrows (*Spizella pallida*). The riparian habitat was used by various passerines during migration. Foraging flocks of mixed species of blackbirds were also encountered.

Methods

Most study sites were searched for dead birds twice weekly during spring and fall. Study periods included July–November 1980, April–May 1981, 1982, and August–November 1981. Bird use of Hendrix Pothole and Halfway Lake was limited; therefore, these sites were searched only once weekly. Portions of the upland along each study segment were searched by two observers walking in a zigzag pattern under one side of the line and returning under the adjacent areas. After initial investigations revealed that dead birds were being removed by scavengers, the Kunkel Lake site was searched three times weekly in fall.

Search areas consisted of the right-of-ways between spans and portions of adjacent land.

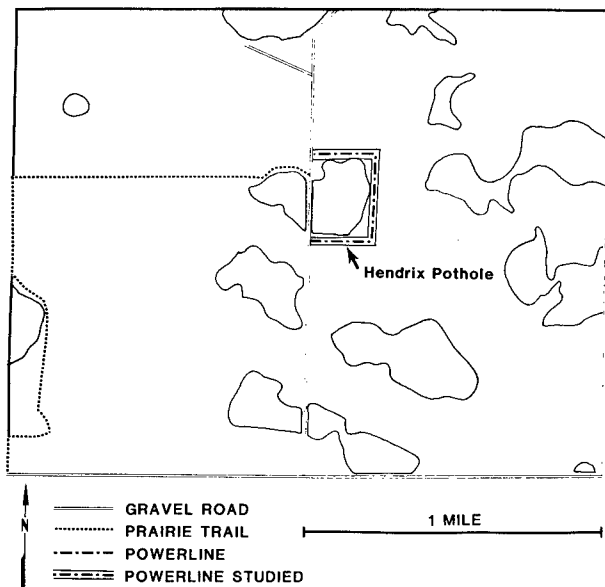


Fig. 8. Location of the power line corridor at the Hendrix Pothole study site.

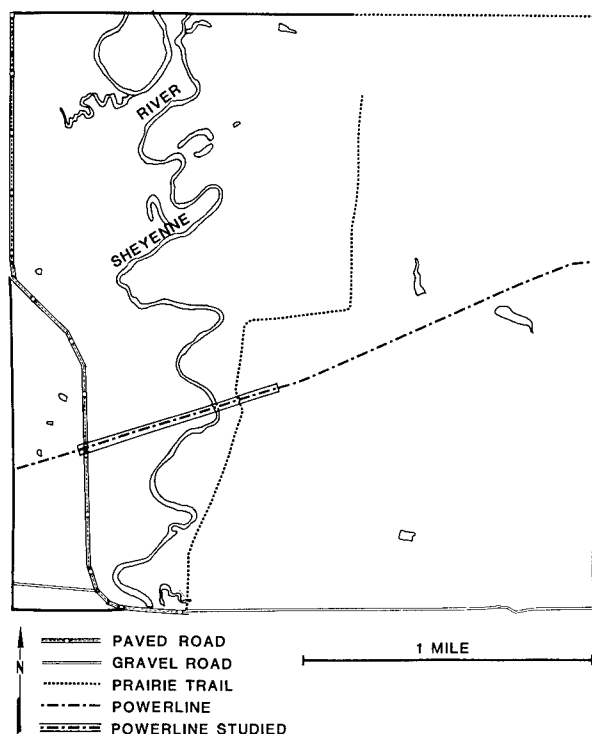


Fig. 9. Location of the power line corridor at the Sheyenne River study site.

Lengths of search areas varied from 0.7 to 1.9 km. Search widths were dependent on the line heights because higher power lines caused birds to fall farther from the center line. On power lines ≥ 230 kV, search widths were 45 m from the edge of the center conductors. At Hendrix Pothole, the search width was 15 km from the center line.

Searches for dead birds were conducted as early in the day as possible to reduce the number of birds lost to scavengers. Two study sites were searched each day, generally between sunrise and 1000 h. Search times were alternated so each site was visited at dawn at least once weekly. The location of each dead bird or feather spot (a group of feathers remaining after scavenging or decomposition) found was marked on a map of each study site. Dead birds and feather spots were collected and removed from the area during each search.

All birds found dead or injured under the lines were examined to determine the probable cause of death or injury. The following data were recorded for each dead bird found: species, sex, age, physical condition (broken bones, lacerations, abra-

sions), and other observable signs of death, including gunshot wounds.

To estimate the amount of loss to scavengers, we placed a known number of dead birds under the wires at each site during each season. Birds of various species were used to simulate actual mortality caused by the power lines. The marked birds were monitored two or three times weekly to determine their rate of disappearance. Radio transmitters were attached to dead and injured sandhill cranes and Franklin's gulls during fall 1981 to monitor their removal by scavengers.

Observer error in searches for dead birds was examined by having another person place a known number of dead birds beneath each search line at each site. The principal investigators walked the searched area and recorded the number of placed birds they found. A comparison of the number of marked birds found with the number placed provided a basis for determining observer error.

The number of live birds present at each study site was estimated before each search. In upland study sites, bird populations were estimated by recording the number of birds on two plots in each habitat type. Surveys of water birds were made by estimating the number present before each search. Avian numbers were not determined with standardized sampling techniques, nor were the data gathered daily throughout the study periods. The data provided relative population indices that cannot be used to determine bird mortality rates at power lines. Throughout the test, values for populations by time period are the mean values combined between years for those periods.

Data were gathered to determine bird movements, flight intensities, behavior, and reactions to power lines within each study area. Nocturnal observations were conducted during fall 1980 but were discontinued because few birds were observed at night. Primarily, we determined the number of birds passing above, beneath, and through the power lines. Observations were made during early morning (0.5 h before sunrise to 0900 h) and evening (2 h before sunset to 0.5 h after).

Data collected for each flight of birds observed included flight altitude, reaction of the bird(s) to the presence of the ground wire or conductor, the distance from the power line when the bird flock reacted to the presence of the ground wire or conductor, and the altitude maintained by the bird(s).

after crossing the exit zone. The exit zone was that portion of airspace from the ground wire or conductor out 15 m.

The following data were gathered for each flight of birds approaching the power lines: time, flock size, species or type of bird, approach height, crossing height, and exit height. Height above ground was divided into six categories (Fig. 1): Zone 1—ground level to the base of the conductors; Zone 2—area between conductor and ground wire; Zone 3—top of the ground wire to 3 m; Zone 4—3–8 m above ground wire; Zone 5—8–15 m above ground wire; and Zone 6—>15 m above ground wire.

Reactions exhibited by birds in flight were placed in eight categories: (1) no reaction, maintained constant altitude and unaltered flight; (2) flared and crossed higher than original altitude; (3) flared and continued to climb after crossing into the exit zone; (4) aborted flight upon seeing power line, reversed flight, and continued flying away from power line (usually occurred at least 50 m from the power line); (5) turned and left area (usually occurred more than 50 m of the power line); (6) flared from power line and left area (usually occurred within 50 m of the power line); (7) crossed and then recrossed the power line; and (8) landed and sat on the ground wire or conductor.

Data Analysis

All field data collected during this investigation were recorded on field sheets, and then entered into a computer system for later analysis. Various bias and expansion factors were calculated for each study site by totaling values for each year and obtaining mean values for each variable. Included in this effort were calculations of the number of dead birds not recorded because of observer error, scavenger removal, habitat, and crippling loss. The formulas for these factors (adapted with one minor correction) are from Beaulaurier (1981).

Search bias was a measure of observer error in finding dead birds at the power line sites. The formula for calculating search bias was

$$SB = \frac{TDBF - PBF}{PBF}$$

where

SB = search bias

TDBF = the total number of dead birds and feather spots found at each site during the study

PBF = the proportion of birds found of those placed during observer error experiments

Scavenger removal was calculated with the assumption, based on field studies, that 10% of the birds planted for removal studies were removed before the search. Removal bias was calculated by

$$SR = \frac{TDBF + SB}{PNR} - (TDBF + SB)$$

where

SR = scavenger removal

PNR = the proportion of planted birds not removed by scavengers (this number was assumed constant at 0.9 for each site)

A *habitat expansion factor* was calculated to account for differential search abilities resulting from the degree of vegetation cover. Habitat bias was calculated by

$$HF = \frac{TDBF + SB + SR}{PS} - (TDBF + SB + SR)$$

where

HF = habitat expansion factor

PS = the proportion of the study area that was searchable

Crippling bias was a measure of the number of birds that struck a power line, but continued flying out of the search area. This statistic was calculated by assuming that 74% of the birds that hit a power line continued flying out of the area. This figure is the average of values recorded by Meyer (1978) and James and Haak (1979), and reported by Beaulaurier (1981).

The *estimated total collisions* for each site equal the sum of the number of dead birds found plus the bias estimates:

$$ETC = \frac{TDBF + SB + SR + HF}{1 - CB}$$

where

CB = crippling bias
ETC = estimated total collisions

Results

Searches for Dead Birds

Six hundred thirty-three dead birds were found beneath the power line study sites. The seasonal breakdown included 122 in spring and 511 in fall. The number of dead birds was greatest at Sibley Lake where 205 were found, representing 32% of the total observed mortality. The 164 birds found at Kunkel Lake formed about 26% of total mortality. The combined total for the four water bird concentration areas was 596 birds, or 94% of the total. These percentages were consistent between years. Avian mortality at the water bird production wetlands totaled 20 birds (3%), and 17 birds (3%) were found at the wooded river valley site.

Waterfowl made up 26% of total mortality, 24% of fall mortality, and 38% of spring mortality (Table 1). Gulls made up the second highest mortality among bird groups, with 23% of the total.

The Franklin's gull accounted for most gull mortality. Dead Franklin's gulls were commonly found beneath the power lines during fall migration, but seldom in spring, as Franklin's gulls gathered in large flocks only during fall migration. Similarly, most of the sandhill crane mortality occurred during fall migration (93%), reflecting the tendency of sandhill cranes to form large aggregations in central North Dakota only during fall migration; they are, however, uncommon in spring. The largest number of dead sandhill cranes was found at Sibley and Kunkel lakes.

Comparison of mortality and bird populations during 10-day periods in fall (Fig. 10) revealed that peak mortality was consistent with peak numbers of birds present. This finding suggests that periods when high mortality from power lines occur may be predictable.

Physical evidence of collision with a solid object was found in 74% of the dead birds. Cause of death for the remaining 164 birds was unknown. No mortality from gunshots was evident. Typical injuries included broken wings, broken legs, lacerations, puncture wounds, and abrasions. Faanes (unpublished report) provided a description of internal and external wounds exhibited on dead birds during the 1980 field season. Fresh kills (i.e., those

Table 1. Total dead birds found, by major avian groups and seasons, at seven study sites in North Dakota, 1980-82.

Group	No. dead birds found					
	Spring	(%)	Fall	(%)	Total	(%)
Waterfowl	46	(37.7)	120	(23.6)	166	(26.2)
Gulls	14	(11.5)	129	(25.3)	143	(22.6)
Cranes	4	(3.3)	58	(11.2)	62	(9.8)
Shorebirds	9	(7.4)	43	(8.4)	52	(8.2)
Rails and coots	11	(9.0)	35	(6.9)	46	(7.3)
Cormorants	0		40	(7.8)	40	(6.3)
Other passerines	14	(11.5)	16	(3.1)	30	(4.7)
Blackbirds	8	(6.6)	18	(3.5)	26	(4.1)
Grebes	4	(3.3)	8	(1.6)	12	(1.9)
Unknown	0		11	(2.2)	11	(1.7)
Grouse	4	(3.3)	7	(1.4)	11	(1.7)
Pelicans	0		10	(2.0)	10	(1.6)
Raptors	2	(1.6)	8	(1.6)	10	(1.6)
Doves	5	(4.1)	3	(0.4)	8	(1.3)
Hérons	0		3	(0.4)	3	(0.5)
Woodpeckers	1	(0.8)	2	(0.4)	3	(0.5)
Total	122		511		633	(100.0)

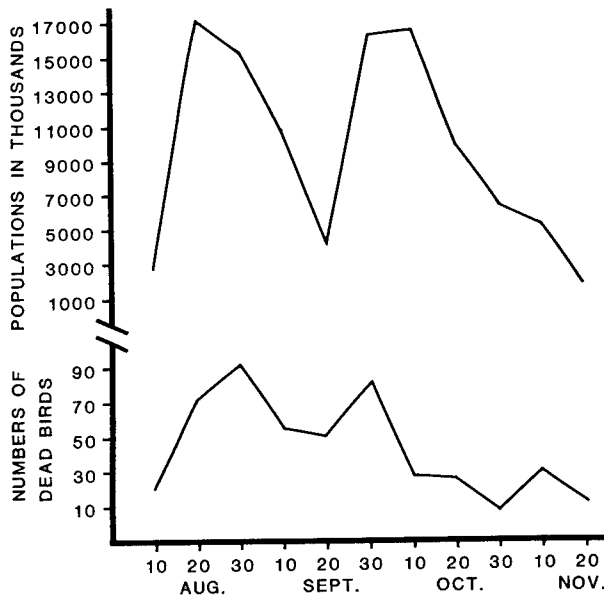


Fig. 10. Relations between avian numbers at study sites and observed mortality during fall migration.

found within 3 days of death) were most numerous, totaling 412, or 65% (Table 2). Bird mortality as indicated by feather spots totaled 135 (21%). Birds in various stages of decomposition totaled 57, including 27 birds with only wings remaining, and two with only the head remaining.

Collision and Mortality Estimates

Mortality data for each site and season were pooled among years. These data were then subjected to several bias estimates to provide esti-

Table 2. *Physical condition of dead birds found beneath power line study sites in North Dakota, 1980-82.*

Condition	No. dead birds found			(%)
	Spring	Fall	Total	
Fresh	76	336	412	(65.0)
Feather spot	32	103	135	(21.4)
Wing only remaining	4	23	27	(4.3)
Head only remaining	0	2	2	(0.3)
Decomposition beginning	10	47	57	(9.0)
Total	122	511	633	(100.0)

mated total kills and estimated number of collisions with a power line (Table 3); total estimated mortality was 1,332 birds. Highest mortality occurred at Cherry Lake where 29% of the dead birds were found. Kunkel Lake made up 26% of the estimated mortality and collisions, and Sibley Lake made up nearly 23% of this total.

Overall percentages of total mortality at study sites changed little throughout the study. The large water bird concentration areas accounted for 92% of the estimated kills and collisions, and water bird production wetlands and the wooded river valley site each made up 4% of the total.

Dead Bird Necropsies

To verify the accuracy of field diagnosis, 11 birds found beneath the power line study sites in 1980 were submitted to the National Wildlife Health Laboratory, Madison, Wisconsin, for necropsy. These individuals were selected to reflect differences in size and also different study sites. Birds in this sample included four ducks, two shorebirds, one gull, one coot, one grebe, one cormorant, and one sparrow. Ten of the 11 birds were of sufficient size to necropsy. All 10 birds were diagnosed as having died from trauma caused by striking some solid object. The most frequently mentioned cause of death was massive or extensive hemorrhage in the thoracic cavity. An injury of this type probably results from colliding with a solid object, rather than from falling to the ground (G. L. Pearson, D.V.M., personal communication).

All birds found in subsequent years were examined in the field to determine the extent and type of external injury. No evidence was found to suggest that injuries were resulting from causes other than collisions with a solid object. Hunter activity at the study sites was practically nonexistent during our observations, and no birds had gunshot wounds.

Bird Flight Observations

Data were collected on 7,596 bird flights. A bird flight consisted of one or more birds physically independent from others, flying through the power line corridor. The most numerous birds observed were Franklin's gulls, sandhill cranes, red-winged blackbirds, yellow-headed blackbirds, and several

Table 3. *Estimates of total mortality and total collision with power lines at seven study sites in North Dakota, 1980-82.*

Site	Line span (km)	Line type (kV)	Observed mortality	Estimated dead birds	Estimated total collisions
Cherry Lake	1.9	230	129	388	1,488
Kunkel Lake	1.1	230	164	353	1,357
Sibley Lake	1.8	400	205	297	1,142
Chase Lake	1.8	230	98	192	738
Sheyenne River	1.1	230	17	46	177
Halfway Lake	1.2	230	10	29	108
Hendrix Pothole	0.7	12	10	28	108
Total	9.6	—	633	1,332	5,118

waterfowl species. During spring migration, the largest number of flights at all sites was recorded in mid-April, with a secondary peak during the first 10 days of May (Table 4). The early movements coincided with peak flights of waterfowl and initial movements of shorebirds. The May peak consisted principally of shorebirds and passerines. During 11-20 May, one-third of all flights recorded were passerines at the Sheyenne River site.

Two numerical peaks of abundance were also observed during fall migration (Table 5). The first peak, during 11-20 August, involved about 19% of the total flights and was primarily Franklin's gulls; shorebird numbers also peaked during this period. The number of flights observed during 21 August-20 September was much lower, corresponding with the general egress of Franklin's gulls and shorebirds.

The second fall peak occurred 21-30 September, coincident with the first sandhill cranes to arrive in the lake region of Kidder County and the peak

blue-winged teal migration. The number of flights observed slowly declined during October and the first week of November. Water began to freeze after 10 November each year, causing most waterfowl and sandhill cranes to depart. By mid-November, few birds remained on the study area and the last large lakes froze about 15 November each year.

Among the 7,051 flights having sufficient data for analysis, two-thirds exhibited no reaction to the power lines (Table 6). Results in both seasons were similar (68% in spring and 67% in fall). The next most common reaction of flocks was to see the power line (apparently most often the conductor) and then flare to climb in altitude until they were safely over the ground wire. This reaction was shown by about 25% of all flights throughout the year—28% in spring, and 24% in fall. Although these data were not analyzed for species, general observations suggested that Franklin's gull was the species most susceptible to the pres-

Table 4. *Bird flights observed at seven study sites in North Dakota during two spring migrations, 1981 and 1982.*

Site	April			May		Total
	1-10	11-20	21-30	1-10	11-20	
Sheyenne River	8	90	7	139	218	462
Halfway Lake	7	55	28	75	98	263
Hendrix Pothole	32	46	44	33	53	208
Chase Lake	105	119	82	172	127	605
Kunkel Lake	25	396	79	183	67	750
Sibley Lake	27	10	55	43	42	177
Cherry Lake	0	23	142	21	57	343
Total	204	739	437	766	662	2,808

Table 5. *Bird flights observed at seven study sites in North Dakota during two fall migrations, 1980 and 1981.*

Site	August			September			October			November	
	1-10	11-20	21-31	1-10	11-20	21-30	1-10	11-20	21-31	1-10	11-20
Sheyenne River	11	176	40	73	58	52	50	—	—	—	—
Halfway Lake	17	55	7	15	23	2	16	—	—	—	—
Hendrix Pothole	37	66	33	29	76	72	54	—	—	—	—
Chase Lake	157	136	26	72	30	103	69	40	53	23	6
Kunkel Lake	39	417	334	89	102	162	112	85	190	148	18
Sibley Lake	28	13	53	44	23	193	115	161	183	133	10
Cherry Lake	6	50	34	63	87	49	84	36	22	17	11
Total	295	913	527	385	399	633	500	322	440	321	45

ence of a conductor or ground wire, and most of the fall observations of this reaction were attributed to that species.

Birds that aborted flights upon seeing a power line made up 99 of the total flights, or 17%. Most of these were Franklin's gulls. Less than 1% of the birds observed either continually crossed and recrossed the power lines, or sat on a line (usually a ground wire). Swallows most frequently recrossed; species sitting on a line were either swallows or raptors.

At all sites, flaring and climbing over the power line (Table 7) was the second most common reaction. This reaction was usually exhibited in Zone 3. Of the 1,782 flights exhibiting this reaction, 1,118 or 63% were in Zone 3. This reaction was especially evident among Franklin's gulls.

In 82 flights, 109 birds struck a wire while observations were being recorded (Table 8). In total, 102

(93%) birds collided with the ground wire, and 7 (7%) struck the conductor. During 1980, 46 birds collided with a power line, and 39 (85%) of these encountered the ground wire (Faanes unpublished data). The range of bird flight sizes involved in a collision was 1 to 1,000. The observed collision rate during this study was about 1% (82 of 7,596 total observed flights).

Most collisions were observed in early evening. The largest number of birds seen colliding at one time was eight Franklin's gulls at Kunkel Lake in mid-August 1981, and 19 Franklin's gulls in late August 1980. These birds collided within 15 min of sunset on clear nights with light north winds. More than 61% ($N = 67$) of all observed bird collisions occurred at the Kunkel Lake site. The most commonly observed reaction that resulted in a collision was flaring and climbing, which made up 87% of the total.

Table 6. *Reactions exhibited by birds in flight at all power line study sites in North Dakota, 1980-82.*

Reaction	No. birds observed					
	Spring	(%)	Fall	(%)	Total	(%)
No reaction	1,780	(37.2)	3,016	(62.8)	4,776	(68.0)
Flared and climbed	732	(41.0)	1,050	(59.0)	1,782	(25.3)
Flared and continued climbing	57	(30.1)	132	(69.9)	189	(2.7)
Aborted flight and turned	40	(40.4)	59	(59.6)	99	(1.4)
Flared and went under structures	25	(32.0)	53	(68.0)	78	(1.1)
Crossed and recrossed	3	(6.5)	43	(93.5)	46	(0.7)
Flared and left area	6	(19.3)	25	(80.7)	31	(0.4)
Sat on wire	1	(3.7)	26	(96.3)	27	(0.4)
Total	2,645		4,406		7,051	

Table 7. Total flights and flock reactions within each power line zone (see text for explanation of zone heights and location) at all study sites in North Dakota, 1980-82.

Reaction	Zone						Total	(%)
	1	2	3	4	5	6		
No reaction	1,679	314	850	842	603	456	4,744	(68.0)
Flared and climbed	6	204	1,118	389	61	4	1,782	(25.4)
Flared and continued climbing	1	7	139	40	0	1	188	(2.7)
Aborted flight and turned	14	49	15	3	0	1	82	(1.2)
Flared and went under structure	53	22	2	0	1	0	78	(1.1)
Crossed and recrossed	13	7	13	6	4	2	45	(0.6)
Flared and left area	1	9	18	1	0	1	30	(0.4)
Sat on wire	1	5	18	0	0	0	24	(0.3)
Total	1,768	617	2,174	1,281	669	465	6,973	
All flights in zone (%)	(25.3)	(8.9)	(31)	(18.4)	(9.6)	(6.7)	(100.0)	

Observer Error and Scavenger Removal Experiments

Scavenger removal experiments, using dead birds, were conducted at all sites during the spring and fall migration periods. The species of birds used ranged from the northern flicker (*Colaptes auratus*) to the sandhill crane. Scavenger removal was virtually nonexistent at most sites during 1981 or 1982, as planted birds remained undisturbed for as long as 2 weeks before decomposing.

Scavenger removal was a problem at Kunkel Lake during fall migration in 1980. During the first experiment at Kunkel Lake, five ducks were planted on 15 August; by 17 August, all five had been removed. Five more ducks were planted on 17 August at 1630 h, and by 18 August at 0800 h all five birds had been removed. On 19 August, five ducks were again planted, and these had been removed by 20 August. Two Havahart live traps were baited with dead American coots and placed in the wetland vegetation on that date. Two adult

raccoons (*Procyon lotor*) were trapped on 22 August; a third was captured on 23 August. Removal experiments were then discontinued to avoid providing additional food sources which may have attracted more scavengers.

During fall migration in 1981, virtually no scavenger removal problem occurred at any site until late October, when several partially eaten sandhill cranes were found at Sibley Lake. Three dead radio-tagged sandhill cranes were placed beneath the single span where most of the scavenging was occurring. These birds remained in place 11 days before one was removed. On the twelfth day, we tracked the movement of one removed bird and found in about 300 m away. The carcass had been partially buried and tracks at the site indicated that an American badger (*Taxidea taxus*) had removed the crane.

I performed a scavenger removal test with two injured Franklin's gulls at Kunkel Lake in late August 1981. Each bird suffered from two broken wings after flying into the ground wire. The birds were marked with radio transmitters and moni-

Table 8. Reactions exhibited by birds in flight that resulted in a collision with a power line structure.

Reaction	No. birds observed				(%)
	1980	1981	1982	Total	
No reaction	9	4	0	13	(11.9)
Flared and climbed	40	52	3	95	(87.1)
Flared and went under structure	1	0	0	1	(1.0)
Total	50	56	3	109	(100.0)

tored for 3 days before both died. During that period, movements were limited to 2-3 m from their original location. I had hypothesized that injured birds would move about and be more conspicuous to a scavenger; however, neither bird was removed by a scavenger and the birds remained in place until after decomposition had begun.

During spring migration in 1982, no difference from previous years was discernible in scavenger removal. Seven to 10 birds were placed at each site throughout the period, but the only observed removal occurred at Chase Lake where a yellow-headed blackbird disappeared 1 week after planting, and a Swainson's hawk (*Buteo swainsoni*) at the Sheyenne River site was removed after 9 days. A red fox (*Vulpes vulpes*) was probably responsible for the removal at Sheyenne River.

Populations and Movements

The study periods coincided with the migration of most species, and the data enable useful comparisons. During spring migration each year, most geese had departed for northern nesting areas in early April, generally before the initiation of field work; data for these species are incomplete. Population data for the fall migration were gathered throughout the main migration periods of virtually all bird species using wetland, prairie, and riparian woodland habitats in this region of the northern Great Plains.

Populations during spring migration were characterized by a gradual buildup during late April, reaching peak numbers during 1-10 May at the wetland and prairie study sites. These numbers generally coincided with the regular influx of blue-winged teal and shorebirds during late April, and typical peak populations during early to mid-May. At the Chase Lake site, increases in bird numbers resulted primarily from a rapid increase in the American white pelican population. Use of riparian woodlands along the Sheyenne River reflected the general northward pulsing movement of passerines during late April and early May. Large numbers of birds are usually recorded throughout eastern North Dakota about 10-15 May, and a rapid decline in numbers usually occurs thereafter.

Fall migration at the wetland sites was characterized by two numerical peaks (Fig. 10). The first occurred during mid- to late August, and the sec-

ond from late September to mid-October. The early peak coincided with the main movements of Franklin's gulls on Sibley and Kunkel lakes. American white pelicans, especially on Chase Lake, reached peak levels during this period. The number of Franklin's gulls peaked on Sibley Lake in late August each year. Populations of Franklin's gulls throughout the study area diminished rapidly after late August. At the same time, numbers of sandhill cranes began to increase.

The second peak in bird numbers later in the season corresponded to maximum numbers of geese (primarily Canada geese) and, to a lesser extent, ducks. Peak numbers of sandhill cranes were recorded about 1 October at Sibley, Cherry, and Kunkel lakes. In mid- to late October, a general increase in numbers of Canada geese occurred. Smaller peaks observed at Sibley and Chase lakes were related to late influxes of snow geese at these sites in 1981.

Bird populations at Hendrix Pothole peaked during early September and consisted primarily of red-winged blackbirds. Numbers of birds declined rapidly afterwards, corresponding to the general movements of blackbirds out of the region. By early October, most birds had departed this site. Bird numbers at Halfway Lake peaked during late August and included large numbers of blackbirds. By early September each year, wetlands began to dry rapidly and bird numbers also declined rapidly.

Bird numbers at the Sheyenne River site built rapidly through mid- to late August, reaching a peak during the first 10 days of September. The population buildup and peak generally consisted of migrant warblers, vireos, and thrushes. Numbers dropped sharply after the early September peak. A general influx of sparrows was observed during late September. However, by early October each year, only nonmigratory species such as the black-capped chickadee, white-breasted nuthatch, and downy woodpecker (*Picoides pubescens*) remained.

Site-specific Investigations

Detailed descriptions of bird use, mortality, and bird flights follow, to show how individual site characteristics affected bird mortality and movements.

Sibley Lake

Dead Birds

Two hundred five dead birds found at Sibley Lake were the most recorded during the study (Table 3). Twenty-nine birds were found during spring surveys and 176 during fall surveys. Gulls were most frequently encountered and made up 21% of the mortality. The sandhill crane was second highest with 40 birds (19%), followed by the double-crested cormorant with 39 birds, also 19% of total mortality. All sandhill cranes but one were found during fall migration.

Seasonal variation in mortality at this site was especially pronounced. Double-crested cormorants were most numerous during fall migration, making up 23% of the season's mortality. High mortality was due primarily to an exceptionally large number of cormorants found during the 1981 fall migration. Passerines, primarily finches, made up more than one-third of all mortality in spring migration.

Mortality along the power line corridor during fall occurred principally along spans 3 and 4 where 50 and 59 birds were found. This area crossed a major southwest-northeast flight corridor. During fall 1980, this corridor was used heavily by Canada geese, and in 1981 by double-crested cormorants. Although this portion of the transmission line route was about 0.4 km from the edge of Sibley Lake, the incidence of strikes was not lowered, as had been earlier hypothesized. I believe the mortality at this site was influenced by the presence of two natural drainageways that served to funnel the birds through specific areas of the power line corridor, and probably increased the incidence of collision.

Bird Flight Observations

Data were analyzed for 1,054 bird flights at Sibley Lake during this study. Sandhill cranes, double-crested cormorants, and Canada geese were the most regularly observed species. The largest number of flights observed was 193 during 21-30 September and 183 during 21-30 October.

Of the flights where bird reaction data were recorded, 779 (74%) involved birds that exhibited no reaction to the power line, and 163 (15%) that flared to climb over the power line. Nearly 55% of

the flights were recorded in Zone 3 and 18% were in Zone 4. The second most frequent reaction observed in Zone 3 was flaring to climb over the power line. Nearly 83% of all observations of this reaction at Sibley Lake occurred in Zone 3. The third most frequent reaction was flaring and continuing to climb, which accounted to 7% of all flights. Most of these reactions involved birds in Zone 3.

During fall migration, most sandhill cranes observed at this site flew away from or toward the lake in a southeasterly direction, thus paralleling the power line up to span 1. Double-crested cormorants, on the other hand, exhibited a north-south flight line through the area, which probably contributed to the number of dead cormorants found.

Cherry Lake

Dead Birds

A total mortality of 129 birds at Cherry Lake was third highest among the sites studied (Table 3), consisting of 18 birds during spring and 111 during fall. Waterfowl made up nearly half of all mortality, followed by shorebirds (14%) and gulls (13%). This pattern of abundance was identical in spring and fall.

Mortality during fall was evenly distributed wherever the power line was in proximity to the large water body. Nearly 70% of the dead birds were found beneath spans 3, 4, and 5, which were closest to the lake. Only 21 birds (16%) were found beneath span 1, which crossed open water for most of its length. The presence of water may have contributed to observers finding fewer birds there because wave action could easily carry birds away from the search area.

Bird Flight Observations

Data were collected on 719 bird flights at Cherry Lake during this study. Sandhill cranes, shorebirds, and several waterfowl species accounted for most of the observations. The largest number of flights observed at this site was 142 during 21-30 April and 87 during 11-20 September.

Of the flights where reaction data were recorded, 519 (72%) involved birds that exhibited no reaction to the power line and 121 (17%) that flared to climb over the line. About 41% of the flights

were recorded within Zone 1 and 21% were in Zone 3. The second most frequent reaction among birds in Zone 1 was flaring and going under the conductor (5%). This reaction occurred among waterfowl and shorebirds as they flew to and from the lake while on feeding flights.

The most frequently observed reaction among birds in Zone 3 was flaring to climb over the power line (47%), whereas birds exhibiting no reaction in this zone made up 40% of the total.

Kunkel Lake

Dead Birds

One hundred sixty-four dead birds were found at Kunkel Lake during this study (Table 3). Twenty-eight birds were found during spring and 136 during fall. Franklin's gull was the most numerous species, making up 49% of the total. All Franklin's gulls were found during fall migration. This gull was the most numerous species at Kunkel Lake throughout the study. Sandhill cranes were the second most numerous, and ring-billed gulls (*Larus delawarensis*) ranked third.

Gulls accounted for 40% of the mortality, followed by waterfowl with 21%. Waterfowl made up most of the mortality during spring migration with about 46% of total mortality. Gulls made up about 47% of the fall mortality.

More than 81% of the dead birds were found beneath span 2. Mortality at the other spans was evenly distributed and was consistent throughout the investigation, with 93% during 1981 and 75% during fall 1980. Span 2 crossed the nearest point between Kunkel Lake and nearby fresh wetlands and thus crossed a major flight line for Franklin's gulls moving between feeding and roosting sites. The flight pattern of sandhill cranes during fall 1980 crossed the northern end of the lake, but in 1981, most sandhill cranes were observed flying into or away from Kunkel Lake in easterly or southerly directions. This change resulted from different cropping practices in 1981 that provided suitable food sources in an opposite direction from the previous fall.

Bird Flight Observations

Data were collected on 2,318 bird flights at Kunkel Lake. Franklin's gull was by far the most frequently observed species at this site. Sandhill

cranes were of secondary abundance, and Canada geese added to the total later in fall. The largest number of flights observed was 396 during 11-20 April and 417 during 11-20 August. The latter period corresponded with peak populations of Franklin's gull.

Of the flights where reaction data were recorded, 1,130 (49%) involved birds that exhibited no reaction and 1,026 (44%) involved birds that flared to climb over the power line. The proportion of birds exhibiting these two reactions varied considerably. During spring 1981, 31% of all flights involved no reaction and 62% involved flaring, whereas during fall migration in 1981, 56% involved no reaction, but only 36% involved flaring.

About 40% of all flights observed at Kunkel Lake were in Zone 3 and 25% were in Zone 4; only 11% were in Zone 1. The most frequently observed reaction in Zone 3 was flaring to climb over the power line (70%); no reaction was second most frequent (21%). General observations suggest that most birds exhibiting flaring reactions, especially those in Zone 3, were Franklin's gulls.

Chase Lake

Dead Birds

Ninety-eight dead birds were found at Chase Lake, 31 in spring and 67 in fall (Table 3). Franklin's gull was most numerous during fall 1980, making up 13% of the mortality (Faanes, unpublished report); gadwall and blue-winged teal were second in abundance. The seasonal breakdown of mortality among waterfowl included 16 birds in spring and 24 during fall. Waterfowl made up 41% of the total, followed by gulls (22%) and American coots (7%).

Mortality occurred principally between spans 2 and 3, with span 2 accounting for 29% (28 birds) of the mortality and span 3 for 26% (26 birds). Span 1 accounted for 13 dead birds, span 4 for 17, and span 5 for 14.

Bird Flight Observations

Data were analyzed on 1,320 bird flights at Chase Lake, 605 during spring and 715 during fall. American white pelicans, several waterfowl species, and California and ring-billed gulls made up most of the observations. The largest number of flights observed included 172 during 1-10 May

and 157 during 1-10 August. The latter period coincided with movements of double-crested cormorants and shorebirds in the area.

Of flights where reaction data were recorded, 874 (73%) involved birds that exhibited no reaction and 262 (22%) involved birds that flared to climb over the power line. About 24% of all flights observed at Chase Lake were in Zone 3 and 22% were in Zone 4. The most frequently observed reaction in Zone 3 was flaring to climb over the power line (52%), whereas 41% of the flights in this zone exhibited no reaction. Of those flights observed in Zone 4, 74% exhibited no reaction and only 22% flared. More than 92% of the birds in Zone 1 exhibited no reaction.

Hendrix Pothole

Dead Birds

Field work during fall was curtailed after the first week in October 1980 and 1981 because most birds departed after the start of the waterfowl hunting season. Ten dead birds were found at Hendrix Pothole (Table 3) and included five ducks, two American coots, two blackbirds, and one grebe. Mortality along this power line appeared to be randomly distributed.

Bird Flight Observations

Data were collected on 575 bird flights at Hendrix Pothole, 208 in spring and 367 in fall. Yellow-headed blackbirds, red-winged blackbirds, and several species of dabbling ducks (especially mallard and blue-winged teal) made up most of the observations. The largest number of flights recorded at this site was 53 during 11-20 May and 76 during 11-20 September.

Of the flights where reaction data were recorded, 394 (79%) involved birds that exhibited no reaction and 84 (17%) involved birds flaring to climb over the power line. About 26% of the flights observed at this site were in Zone 3 and about 20% were in Zones 1 and 4. The most frequent reaction observed within these zones was no reaction (76% of all flights).

Halfway Lake

Dead Birds

Ten dead birds were found at Halfway Lake. Waterfowl made up 50% of the observed mortal-

ity (Table 3). Seven of the dead birds were found beneath span 1, which crossed between two seasonal wetlands. Two dead birds were found beneath span 3, which was associated with one seasonal wetland. The two gray partridges (*Perdix perdix*) found at this site were typical of upland habitats.

Bird Flight Observations

Data were collected on 398 bird flights at Halfway Lake, 263 during spring and 135 during fall. Blackbirds and dabbling ducks made up most of the observations. The peak number of flights included 98 during 11-20 May and 55 during 11-20 August.

Of the flights where reaction to the power line was recorded, 273 (80%) exhibited no reaction and 65 (19%) flared to climb over the power line. About 65% of the flights were within Zone 1 and 12% were in Zone 2. Of those flights in Zone 1, all but two showed no reaction, whereas 25 of 41 in Zone 2 flared to climb over the power line. No bird collisions were observed at this site.

Sheyenne River

Dead Birds

Field work was initiated in late April each year because few migrant woodland birds arrive in eastern North Dakota before that time. Fall field work was stopped about 10 October after the major movement of migrant woodland birds had passed.

Seventeen dead birds were found at the Sheyenne River (Table 3). Passerines made up the bulk of the kill with 35% of the total, followed by doves and woodpeckers (18% each). Fourteen birds (82%) were found beneath span 2, which included the riparian woodland and the edge of a crop field. Two birds were beneath span 1, which crossed upland native prairie, and one bird was found beneath span 4, which crossed a county highway and upland native prairie. No birds were found beneath span 3, which crossed cropland.

Bird Flight Observations

Data were collected on 922 bird flights at the Sheyenne River site. This total was almost identical between seasons, 462 during spring and 460 during fall. Mourning doves (*Zenaidura macroura*), red-winged blackbirds, and several species of pas-

serines including warblers, thrushes, flycatchers, and gray catbirds (*Dumetella carolinensis*) were most commonly observed. The largest number of flights at this site was 218 during 11–20 May and 176 during 11–20 August.

Of the flights where reaction data were recorded, 777 (92%) involved birds showing no reaction and 54 (6%) involved birds that flared to climb over the power line. I observed 586 flights (69%) in Zone 1 and 106 (13%) in Zone 2. Of those in Zone 1, 99% showed no reaction and 1% flared to go under the conductor, whereas among those in Zone 2, 65% showed no reaction and 25% flared to climb over the conductor.

Discussion

Dead Bird Searches

Waterfowl accounted for most of the observed mortality but ranked third in total abundance at the study sites, behind gulls and sandhill cranes. One condition that seemed to influence waterfowl mortality during spring migration was inattentiveness by males. Several instances of mortality to male ducks were noted when a male or group of males were in aerial pursuit of a female and collided with a power line.

The high percentage of Franklin's gulls among the total mortality, particularly during fall migration, was related to the behavior of this species during migration. Franklin's gull is a locally abundant nesting species on large marshes in North Dakota (Stewart 1975). While on southward migration, Franklin's gulls typically occur in large concentrations on alkali wetlands in central North Dakota, and more than 15,000 gulls are regularly encountered on some wetlands. Most Franklin's gulls found dead in this study were at Kunkel Lake, a site typically supporting large gull concentrations. At Kunkel Lake, virtually all dead Franklin's gulls were found beneath span 2, which crossed the upper portion of the lake, closest to nearby fresh wetlands.

Habitat conditions at Kunkel Lake contributed to the high mortality there. Birds were attracted to alkali wetlands because food is abundant and extensive mud flats provide roosting areas. Because of the high salt content of alkali wetlands, birds must seek fresh wetlands to obtain water

and are required to fly between these wetlands to satisfy their dietary needs. Placing a power line between alkali wetlands and fresh wetlands can lead to substantial mortality.

Sandhill cranes made up the third highest mortality among groups. This species typically occurs in concentrations during fall migration throughout central North Dakota, where they roost on alkali wetlands. The number of sandhill cranes in central Kidder County during mid-October 1982 was estimated at 35,000 birds. Sandhill cranes collide with power lines in areas where the species occurs in abundance, including western Texas (Tacha et al. 1979), Nebraska (Wheeler 1966), and in the southeastern portion of the Central Flyway (Lewis 1974). In most instances, sandhill crane mortality results from birds moving between feeding areas and roost sites. Central North Dakota is especially attractive to this species because of the alkali wetlands and the presence of extensive areas of cropland adjacent to roost sites.

Shorebirds ranked fourth in observed mortality. This group is also attracted to alkali wetlands for feeding and roosting, especially in fall migration. The dietary needs of shorebirds are apparently met on their feeding wetlands, so the amount of inter-wetland movement in this group is probably much reduced when compared with waterfowl or gulls. Mortality among shorebirds results from collisions occurring when birds are arriving from or departing to the next migration staging area along their route.

Collision and Mortality Estimates

In the present study, mortality to migratory birds from collisions with power transmission lines appears to be greater than most other results reported from North America. Lee (1978) summarized two Oregon studies where 60 dead birds were found at a water bird concentration area during 3 months, and 19 dead birds were found at a second area. Lee estimated that at the first site, 0.05% of the estimated total flights resulted in a fatal collision; his collision rate was one per 3,370 flights. The collision rate in my study was one per 86 flights. The total number of flights observed in my study during 3 years was about half of Lee's observations for 3 months, suggesting that local conditions in North Dakota resulted in a greater frequency of observed collisions. I observed no

indication that inclement weather contributed to the number of dead birds found.

Thompson (1978) summarized several studies and reported collision rates of 0.01–0.05%. Meyer (1978) reported 31 dead birds of 12 species found beneath 5.9 km of power transmission line in Oregon. In summarizing several other studies, Wirth Associates (unpublished report) advised that collisions with overhead wires were strongly weighted toward waterfowl, pelicans, herons, and other large species possessing relatively low maneuverability. They went on to state from Boyd (1961), Krapu (1974), and Thompson (1978) that dabbling ducks are more likely to sustain mortality than diving ducks. My research supports these statements. In fact, more than 91% of the observed mortality in this study was made up of nonpasserine birds; most are generally not as maneuverable as the passerines.

The interspersation of habitats on the study areas contributed greatly to avian mortality from power lines in North Dakota. Willard et al. (unpublished report) believed that power lines with the same habitat on each side of them were more likely to cause bird collisions than a line running between two different habitats. They suggested that a bird was less likely to fly from one habitat type to another than to fly across a power line in the same habitat, especially when feeding.

My observations contradict the hypothesis of Willard et al. (unpublished report). The extensive alteration of the northern Great Plains for cropland development has resulted in the loss of much habitat homogeneity in North Dakota. Much of central North Dakota that was once mixed-grass prairie has been converted to various forms of crop production, which greatly increases the mosaic pattern of different habitat types and reduces the probability of having sizable areas of natural habitat. The three study sites that contributed the highest mortality (Table 3) were each characterized by a mosaic of habitat types in proximity to the power line corridors.

Bird Flight Observations

Observations of Franklin's gull, primarily at Kunkel Lake, suggested that this bird may have been affected by the presence of power lines more

than any other species observed in this study. Most of the observed collisions of Franklin's gull resulted from flocks of gulls moving as a group between fresh and alkali wetlands. During one evening in late August 1980, I observed 24 Franklin's gulls collide with the ground wire within a 15-min period. Most of these gulls appeared to be immatures. The collisions occurred as immature gulls at the front of the flock flared to climb over the conductor, encountered the ground wire, and turned to fly away from the site. These birds were followed by about 300 adult gulls. The forward movement of the adult gulls at the rear of the flock seemed to influence the movement of immatures and may have caused them to collide with the ground wire.

Among waterfowl, the diving ducks appeared to encounter few problems when in flight near a power line. I attributed this to their rapid movement from the water and their rapid altitude gain, which was important in carrying them above the ground wire by the time they crossed the power line. James and Haak (1979) reported similar observations for two diving duck species. Dabbling ducks, on the other hand, exhibited much slower flight and were generally slower in gaining altitude to clear the power line. This difference may have contributed to the number of dabbling ducks found dead.

The bird flight data were gathered to record information on movements within various distances above ground. Birds within Zones 1–4 were used in this analysis because they would be most likely to encounter a power line. Zone 3 included the area from the top of the ground wire to about 4 m above the ground wire. Nearly two-thirds of all bird flights within Zone 3 flared to climb over the ground wire. About one-third of the flights within Zone 2 flared to climb, which suggests that birds changing their flight altitude within these zones may be responding to the presence of the ground wire and conductor. Among birds observed colliding with a power line, more than 93% collided with the ground wire. Among all birds colliding, 87% flared to climb before the collisions. In most instances, this involved flaring to clear the conductor and colliding with the ground wire. Others (Thompson 1978; James and Haak 1979; Meyer 1980) have stated that the ground wire contributes the most to bird mortality from power lines.

The Biological Significance of Collision Mortality

Social and ecological aspects affect biological significance. The social aspects relate to public awareness of power lines and bird mortality. Prominent among the concerned public are hunters and conservationists. The ecological aspects relate to the impact of mortality on bird populations locally and throughout the range of a species.

Most studies of bird mortality at power lines have attempted to address the issue of the significance of mortality to a local bird population. Thompson (1978) concluded that losses of waterfowl from power line collisions are probably not biologically significant when considering the total population. Willard et al. (unpublished report), who evaluated the potential effect of a proposed power line in Oregon, concluded that although a measurable rate of mortality by power lines occurs where lines cross aquatic habitats, the significance of this mortality on total populations was unknown. They stated that the probability of significant mortality to waterfowl by a proposed power transmission line was greatest in feeding areas. Stout and Cornwell (1976) summarized records of nonhunting mortality among waterfowl and concluded that collision mortality made up less than 0.1% of the sample. Kroodsma (1978) concluded that collisions with power transmission lines by waterfowl made up a very small part of hunting and nonhunting mortality. My data agree with Kroodsma. Conversely, Drewien (1973) concluded that 37% of observed mortality among sandhill cranes in the Rocky Mountains resulted from power line collisions. Owen and Cadbury (1975) found that 38% of the known mortality among three swan species in England was attributable to power line collisions. However, to more fully evaluate the biological significance of mortality from power lines on populations, the cumulative effect of losses sustained throughout migration must be addressed.

Power lines are a potentially serious hazard to rare bird species. About 72% of the entire world's population of about 130 wild whooping cranes (*Grus americana*) cross the Great Plains twice each year on migration. At least 10 instances of whooping cranes colliding with power lines occurred in Colorado, Idaho, Kansas, Saskatchewan, Texas, and Wyoming. One of three whooping cranes born

in the wild in 1981 died after colliding with a power line near Saskatoon, Saskatchewan, in September 1981. A second bird from the 1981 production was killed by colliding with a power line near Waco, Texas, in October 1982. That bird had been observed on the ground about 10 km north of the Kunkel Lake study site 2 days before it was found dead in Texas.

A major part of avian mortality from collisions with power lines can be avoided through careful planning. When power line routes intersect important flight lines near areas supporting large bird concentrations, substantial mortality occurs, as observed at Cherry, Kunkel, and Sibley lakes, where power lines were placed close to the edge of the water. These three sites accounted for 75% of the observed mortality in my study. Power lines placed across major feeding flight lines or natural drainageways that act to funnel the birds seem to contribute to increased mortality at specific sites. Additional research on methods for reducing bird mortality from power lines, such as ground wire removal, sleeving, or marking, needs to be conducted to determine ways to reduce the losses that are occurring.

Control of Bird Losses from Power Line Collisions

My findings and a review of available literature provide a basis for making several recommendations concerning the siting and design of power lines.

Water Bird Concentration Areas

One of the most important ecological factors contributing to avian mortality from power lines in the northern Great Plains is the juxtaposition of line placement with wetlands that support concentrations of water birds. My study revealed that more than 90% of the observed mortality occurred at sites supporting large concentrations of water birds (Table 3). Among the sites I examined, power lines situated 400 m or more from the edge of the water generally had lower observed mortality than sites where the power line was within this distance.

From information obtained in this study and at other sites in western North America, I believe that the distance of power lines from the edge of the water, in areas of high bird collision potential,

affects the rate of avian mortality and merits further investigation. Mortality can occur at sites where extensive low altitude bird flights are associated with a power line crossing close to the water's edge (Kunkel Lake) or directly through a wetland (Malcolm 1982). It may not be justifiable economically to reroute an existing power line except in instances where avian mortality is extremely high. Avoidance of known water bird concentration areas during the route planning stage is probably the most cost effective method of lowering avian mortality levels. A first step in identifying potential risk areas is to identify large wetlands. Information on the use of particular sites by birds can usually be obtained from each State's Department of Natural Resources, or the U.S. Fish and Wildlife Service's Habitat Resources Field Offices, or National Wildlife Refuges.

Avian mortality from power lines also occurred at small wetlands, but at a much lower rate than larger alkali wetlands (Table 3). About 70% of the observed mortality at the Halfway Lake (small wetland) study site occurred at a single span that crossed two seasonal wetlands. Five of seven birds found beneath this span were along the segment of power line that passed adjacent to two seasonal wetlands. These findings reflect the high use of seasonal wetlands as major feeding sites for breeding waterfowl (Swanson et al. 1979).

Within the 97,700-km² prairie pothole region of North Dakota, the density of wetland basins averages about 24/km² (H. A. Kantrud, unpublished data). Thus, it may be difficult to avoid placing power lines in nonlethal locations. In such situations, placement near large wetlands should be avoided. It is also important to avoid placing power lines near large semipermanent wetlands that hold water into the fall migration period and are attractive to water birds for a longer time.

My observations of birds in flight at power lines ≥ 230 kV revealed two aspects of placement that may prove useful for future routings. Observations of flying birds and of dead bird distribution suggested that birds tended to avoid the airspace within about 50 m of the towers. Avoidance of the area near the towers was probably caused by the high visibility of the structures. Most of the observed birds appeared to fly over the lines in the mid-span region, and birds were found beneath the mid-span areas.

Consideration should be given to placing towers in locations that will make the structures more visible to flying birds. I believe this is especially important when power lines are to be routed through areas containing seasonal and semipermanent wetlands.

Few dead birds were found at the Hendrix Pothole study site. Birds in flight crossed randomly over this power line and the wooden poles supporting the line. The various locations where dead birds were found beneath this line reflected their random flight paths. I believe that the most effective routing consideration for distribution lines through small prairie wetland areas is to allow a sufficient distance between the water's edge and the power line.

Many thousand hectares of land in the northern Great Plains and upper Midwest have been acquired by State and Federal resource agencies to provide habitat for waterfowl and other birds. Prominent among these lands are National Wildlife Refuges and Waterfowl Production Areas managed by the U.S. Fish and Wildlife Service, and Wildlife Management Areas managed by various State resource agencies. Because of their inherent wildlife values and associated concentrations of bird life, certain Federal laws have been enacted to regulate power line placement through National Wildlife Refuge lands. Specifically, the laws state that no right-of-ways will be approved unless the Regional Director of the U.S. Fish and Wildlife Service has determined the crossing is compatible with the purposes for which the refuge was established. In instances where power line placement is compatible, consideration should be given to maximizing distances from the edge of water to the line, tower placement, and various modifications of the ground wire.

Riparian Habitats

Riparian vegetation in the northern Great Plains provides important habitat for many bird species. Forests located along north-south oriented streams, including the Missouri, Sheyenne, Red, and James rivers (Avery et al. 1976) in North Dakota, are used heavily by migrant passerines. My research in riparian habitats suggests that avian mortality there can be reduced by design and placement changes of power line conductors and ground wires.

Trees at the Sheyenne River site grew about 15–20 m tall. The conductors of the 230-kV power line at the area of greatest sag were about 2–5 m above the vegetation. The open area right-of-way beneath the power line was used extensively for hunting insects by birds perched near the opening and during many short-duration flights beneath the conductors. About 25% of the birds observed in flight during the study (Table 7) and about 70% at this site were in the airspace between the conductors and the ground (Zone 1). Ninety-five percent of these birds showed no reaction when flying beneath the conductors (Table 7).

Passerine birds fly at various heights above 215 m in nocturnal migration (Able 1970). My observations suggest that diurnal movements of passerine birds are principally beneath the conductors. Avian mortality in riparian vegetation may increase when power lines are at or below the forest canopy (Goddard 1975) probably because visibility of the power lines is obscured by foliage. I recommend that future power lines routed through riparian vegetation be designed to keep conductors above the forest vegetation.

Species of Concern

Several areas in the prairie pothole region are well known for their use by species of concern, including the whooping crane. Among these areas are several alkali lakes in central and northwestern North Dakota, and specific reaches of the Platte and Niobrara rivers in Nebraska. I recommend that special consideration be given to avoiding construction of power lines through areas used by these birds. Locations of traditional use areas by whooping cranes can be obtained from the U.S. Fish and Wildlife Service's Habitat Resources Field Offices.

Raptors are regularly given consideration during resource development projects. Data from this study suggest that power lines in the prairie region probably are not a serious hazard to diurnal raptors such as the prairie falcon (*Falco mexicanus*), red-tailed hawk (*Buteo jamaicensis*), Swainson's hawk, or ferruginous hawk (*B. regalis*), or to owls. During my bird flight observations, raptors were frequently seen hunting beneath power lines or perched on towers, but few dead raptors were found. Raptors frequently nested on towers (Gilmer and Wiehe 1977).

Bald eagles (*Haliaeetus leucocephalus*) are locally common along large rivers during migration and winter. Most concentrations of wintering bald eagles in this region appear to be associated with open water areas downstream from dams along the Missouri and Mississippi rivers, or near warmwater discharge areas along the Platte River in Nebraska.

Diurnal movements of bald eagles during the winter are usually from night roost sites (Faanes 1976). Typical feeding activities consist of short flights from a perch site over the water to capture prey and then a return flight to the perch site. Forest vegetation along the stream bank and along open water channels serve to limit bald eagle movements. Thus, most flights are at low altitudes. I believe the greatest potential for collisions with power lines exists in the mid-span area where power lines cross open expanses of river. I recommend that markers be placed on the ground wire where power lines pass through or near known areas of bald eagle concentrations. Jackson et al. (1982) found no negative effect of a 500-kV line on wintering eagles on the Columbia River when the lines studied had a combination of orange marker balls and ground wire removal on various spans.

Topographic Features

Local and migratory movements of many bird species are influenced by topographic features (Welty 1962). Prominent landscape features in the prairie region are rivers, natural basin wetlands, eskers, and natural drainageways that are part of the watershed for intermittent streams. Natural drainageways at Chase and Sibley lakes probably influenced avian mortality at those sites, where more than 55 and 53%, respectively, of the observed mortality occurred at spans that crossed natural drainageways. Flight lanes of birds at concentration areas can often be predetermined according to topographic features. Thus, the location of topographic features in relation to movements of birds should be considered during power line planning, with preferred areas avoided.

Preliminary planning should include a thorough examination of topographic maps and aerial photographs to identify potential high-risk areas. Where power lines must cross natural flight lanes, such as drainageways, I recommend that towers be placed near the middle of the flight lane in order to increase the visibility of the power line. In

instances where engineering feasibility requires that towers cannot be placed within a drainageway, I recommend that the towers be placed as near as possible to one side of the drainageway.

Ground Wire Modification

My data concur with findings of other studies, indicating that most avian mortality at power lines results from collisions with the overhead ground wire. Observations of birds flying at power lines in North Dakota suggest that the primary reason birds collide after flaring to avoid the conductor is their lowered observability of the ground wire. This appears to be especially critical for birds that flare within about 10 m of the conductor and then have a reduced amount of airspace to maneuver around the ground wire. The most effective methods of reducing avian mortality are to remove the ground wire or place markers on it. Beaulaurier (1981) reported that collisions of birds with power lines were reduced by 35 and 69% at two Oregon study sites after ground wire removal. Mortality at the Kunkel Lake site in North Dakota could probably be greatly reduced by removal of the ground wire at one span.

Ground wire removal, however, can diminish reliability of the power grid because lightning strike protection is reduced (Beaulaurier 1981). Lightning strikes are a potential threat to support towers and conductors in the northern Great Plains because power line towers are often the tallest objects in the surrounding areas and so are especially susceptible to lightning strikes. Central North Dakota experiences about 36 thunderstorm days annually, or about 17% of the days between 1 April and 31 October (U.S. National Weather Service, Bismarck, N.D., personal communication). Thunderstorm and lightning strike frequency should be carefully evaluated before ground wires are removed.

Marking ground wires to increase their visibility to birds in flight appears to be a feasible alternative to ground wire removal. Beaulaurier (1981) summarized the results from 17 studies that involved marking ground wires or conductors and found an average reduction in collisions of 45% compared to unmarked lines. Among the most successful methods used to increase visibility of the lines were black-and-white ribbons and orange aviation marker balls. The Bonneville Power Administration recently installed 23-cm orange marker

balls on the ground wire of a 500-kV line crossing the Missouri River in Montana to reduce the incidence of bird strikes (J. M. Lee, personal communication).

Another promising technique to increase observability of the ground wire is to place Spiral Vibration Dampers (Preformed Line Products Company, Cleveland, Ohio) on the wire. Spiral Vibration Dampers are one-piece helically-shaped rods made of polyvinyl chloride. Dampers were developed for placement on conductors and ground wires to control vibration and reduce line wear. This material is available in diameters of 0.8–1.2 cm with a maximum height of about 3.8 cm. Installation of Spiral Vibration Dampers should be made across entire spans of ground wire so that maximum observability is provided.

In high-use areas, observability would be enhanced by installing both orange aviation marker balls and the dampers. Where it is not feasible to sleeve the entire span, priority consideration should be given to marking the mid-span region of the ground wire because of its high degree of bird use. Whereas certain difficulties are inherent in adding markers to existing power lines, because of added stress to the towers, new power lines should be designed to accommodate the stress from various marking techniques.

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Faanes, Craig A. 1987. Bird behavior and mortality in relation to power lines in prairie habitats. U.S. Fish Wildl. Serv., Fish Wildl. Tech. Rep. 7. 24 pp.

Behavior and mortality of birds near power lines in prairie habitats were studied at seven North Dakota sites during 1980-82. The data revealed that measurable amounts of bird mortality occurred at most sites, especially those near alkali wetlands supporting large concentrations of birds. Observations of birds in flight revealed that most are not affected by the presence of power lines. Most of the birds that were observed to collide with a power line collided with the overhead ground wire. Suggestions for reducing or eliminating mortality from power line strikes are provided.

Key words: Power lines, mortality, prairie wetlands, bird strikes, waterfowl, gulls, sandhill cranes, North Dakota, duck, riparian forest.

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1. Effects of Weather on Breeding Ducks in North Dakota, by Merrill C. Hammond and Douglas H. Johnson. 1984. 17 pp.
2. Lethal Dietary Toxicities of Environmental Contaminants and Pesticides to Coturnix, by Elwood F. Hill and Michael B. Camardese. 1986. 147 pp.
3. Effects of Vegetation Manipulation on Breeding Waterfowl in Prairie Wetlands—A Literature Review, by Harold A. Kantrud. 1986. 15 pp.
4. XYLOG: A Computer Program for Field Processing Locations of Radio-Tagged Wildlife, by Wendell E. Dodge and Alan J. Steiner. 1986. 22 pp.
5. Response to Lake Trout and Rainbow Trout to Dietary Cellulose, by H. A. Poston. 1986. 6 pp.
6. DDE, DDT + Dieldrin: Residues in American Kestrels and Relations to Reproduction, by Stanley N. Wiemeyer, Richard D. Poster, Gary L. Hensler, and John R. Maestrelli. 1986, 33 pp.

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